Constructed Wetlands

Borrowing a Concept from Nature

When it comes to global environmental health problems, few—if any—rank higher than water pollution and lack of sanitation. In developing nations, vast numbers of people lack adequate sanitation. According to *Water and Sanitation in the World's Cities: Local Action for Global Goals*, a March 2003 report by the United Nations Human Settlements Programme, 83% of African city dwellers lack toilets connected to sewers; for Asia's cities, the proportion is 55%. The World Health Organization estimates that as of August 2002, 2.4 billion people had no access to basic sanitation, and 3.4 million people, mostly children, were dying each year from water-related diseases. Even in affluent countries, where potable water and sewage treatment are both available, better and/or cheaper treatment is needed for pollution sources including domestic wastewater, runoff and seepage from mines, agricultural runoff, even polluted runoff from giant parking lots and airport runways.

Help is on the way, in the form of an idea borrowed from Mother Nature: constructed wetlands, where aerobic and anaerobic zones are deliberately created to allow microbes to attack waste streams. While constructed wetlands can vary from rectangular ponds to natural-looking swamps, the basic principle of each is to emulate nature by creating conditions conducive to the growth of the desired microorganisms, and then giving them enough time to digest, or degrade, the waste. As James Gusek, a consulting engineer with Golder Associates, puts it, "We have taken Mother Nature and nurtured it in the specific direction we want."

William Mitsch, a professor of natural resources, environmental science, and ecological engineering at The Ohio State University, and editor of the journal *Ecological Engineering*, says constructed wetlands are often used in places that can't afford any other treatment

Wonderfile

methods. "There are thousands of [constructed wetlands] around the world, often treating domestic wastewater," he says. "There are very few wastewater streams that I can think about that somebody has not tried to put through a wetland, although some [applications] are more valid than others."

Cleaner canals. In Baima, China, a series of canals (above) used to collect and channel sewage, commercial wastewater, and stormwater runoff threatened the health of the city's 6 million inhabitants. After just two months, a Restorer system supporting 12,000 plants of 20 native species (below) is reducing odors, eliminating solids, improving water clarity, and reducing bacteria in the effluent that flows to the area's major river.

Ocean Arks International

Attacking Acid Mine Drainage

In the eastern Appalachians alone, Mitsch says, several hundred wetlands have been built to treat acid mine drainage from coal mines. This acidic solution, formed by a chemical reaction between water and minerals, frequently flows from open-pit mines, deep mines, and tailings piles for decades after the mines are closed. The acidic water mobilizes toxic heavy metals (including lead, copper, cadmium, and aluminum) and carries them downstream. Both the acidity and the metals are toxic to fish and other stream organisms.

Gusek and Thomas Wildeman, a professor of mine chemistry and geochemistry at the Colorado School of Mines, have collaborated on an experimental technique for treating acid mine drainage known as a sulfate-reducing bioreactor. In this bioreactor, specialized bacteria reduce sulfate ions (a typical component of many acidic mine drainages) into sulfide ions. The sulfide ions combine with the dissolved heavy metals, forming metal sulfides, which precipitate and are retained in the wetland's organic mass. "We are reversing the reactions that put these metals in solution in the first place," Gusek says. He adds that about 20 of these bioreactors are in operation, ranging from small pilot demonstration units to full-scale systems.

To build these treatment wetlands, a shallow, artificial pond of up to an acre in size is seeded with animal manure (which contains the necessary bacteria) and cellulose-rich waste materials such as wood chips and sawdust (for the bacteria to feed on). "These bacteria need the sulfate in mine water as a nutrient," Gusek says. "You put the bugs in once, and as long as the organic matter lasts, that's how long they will last."

The first large-scale sulfate-reducing bioreactor has been operating effectively since 1996, Gusek says. With quarterly water quality monitoring to check treatment effectiveness, he says, the treatment wetlands should not need a fresh batch of manure and cellulose for 10–30 years.

Compared to conventional treatment systems, the often lower cost, pleasing aesthetics, and reduced need to monitor explain why constructed wetlands are the "dominant technology that has been applied to mine drainage or metals-contaminated waters," says Mark Fitch, an associate professor of civil engineering at the University of Missouri–Rolla. But Fitch, who has studied the use of wetlands for cleaning up lead mining and processing sites, says constructed wetlands are not always the low-cost alternative, because extensive earth-moving can result in higher costs. A recently proposed wetland for a lead-polluted battery recycling site in Missouri was rejected due to the high price tag.

Restoring a Natural Balance

The idea behind constructed wetlands is not new. For thousands of years, the Chinese have used fish ponds to recycle organic waste into fish food, important to their valuable fish trade. Fittingly, China is the site of sophisticated experiments with a biological cleanup system known as the Restorer, designed by the nonprofit Ocean Arks International of Burlington, Vermont.

In Fuzhou, a city of 1.2 million in southern China, 80 kilometers of extraordinarily polluted canals receive sewage from smaller sewer pipes. The Fuzhou Restorer was built in a 500-meter stretch of canal that received sewage from an estimated 12,000 people.

"I could hardly walk through the neighborhood, it was so offensive," says biologist Erica Gaddis, who helped build the system and is now a graduate student at the University of Vermont. Furthermore, because the canals empty into an estuary that is a regional fishery, the sewage was "a public health issue, a quality-of-life issue, and an ecological issue," Gaddis says.

The Restorer technology is the outgrowth of decades of research by Ocean Arks International's founder and president, John Todd, a research professor in the Rubenstein School of Environment and Natural Resources at the University of Vermont. A Restorer is typically planted with 25 species of plants, microbes, and other organisms. The plant roots both house and nourish the microbes that do the actual decomposition.

The goal, says Todd, is to enhance conventional constructed wetland technology with greater biological sophistication. "We try to borrow from a minimum of three ecological domains—for example, marsh, pond, and stream—all of which have different characteristics," he says. "Greater ecological diversity dramatically increases the ability of the system to self-organize, self-design, self-repair, and self-replicate."

Restorers are different from constructed wetlands in other ways, too. The framework of the Restorer that holds plants and associated microorganisms floats. Restorers use an aeration system connected to the electrical grid whereas wetlands tend to be more passive. The need for large amounts of electricity raises costs considerably, but the resulting higher rates of decomposition mean that Restorers can treat more pollution in a smaller footprint than wetlands, which makes them more appropriate to the urban environment, says Gaddis.

Since the Fuzhou Restorer was installed in 2002, "the water is really clear, the odor is gone, the plants are six feet high. . . . It has really changed the atmosphere," Gaddis says. Measurements show that chemical oxygen demand (the total amount of oxygen needed to decay all organic matter in the water) fell from about 100 milligrams per liter to 40 milligrams per liter, indicating a high degree of treatment effectiveness. The city of Shanghai is considering installing Restorers in some of its canals, Todd says.

A Working Technology?

Despite the growing acceptance of constructed wetlands, their design remains a bit of an uncertain art. "They are a little harder to design, because you are trying to work with nature and utilize the energy flows of nature," says Mitsch. "You'd better know how natural wetlands work; you need more finesse, more understanding of nature."

Unlike conventional sanitation engineers, the ecological engineers who design constructed wetlands do not hope to control every aspect of a design. Rather, says Mitsch, ecological engineers aim for "self-design." He says, "We argue that when you design an ecological system, it designs itself—Mother Nature is the chief contractor." While the engineer may plant the system with desirable organisms, nature

Safe Water for All

In June 2003 the International Network to Promote Safe Household Water Treatment and Storage was formally launched to promote simple, low-cost, point-of-use approaches to rapidly increase access to safe water supplies and sanitation services for less-affluent populations. This represents a significant shift away from earlier projects that focused on community-based, rather than household-based, access to water and sanitation. The goal of these efforts is to reduce the number of deaths from waterborne diseases, especially among vulnerable populations. According to the World Health Organization, 3.4 million people worldwide, most of them children, die each year from causes related to unsafe water, sanitation, and hygiene practices.

The impetus for this network began with the Millennium Development Goals set forth by the United Nations in September 2000, which include a call to reduce by half the number of people without sustainable access to drinking water by 2015. The movement gained further support in November 2002 when the United Nations Committee on Economic, Social, and Cultural Rights adopted a formal acknowledgment of the human right to water that also sets forth general criteria for universal enjoyment of the right.

The network was spearheaded by the World Health Organization and will involve numerous collaborating groups, including international health and development agencies, nongovernmental organizations, research centers, professional and industry professional associations, and corporations. Among other objectives, the network will promote independent research to evaluate the cost-effectiveness, health impact, social acceptability, and sustainability of interventions that are presented to the network. The network's guiding principles include involving communities and individuals in developing appropriate water and sanitation improvement strategies, recognizing the role of women in managing household water supplies, and promoting local technologies, resources, and capacity building. **–Erin E. Dooley**

Flowing aid. A new network will promote safer household water in less-affluent areas.

Giacomo Pirozzi/Panos Pictures

will eventually choose which plants and microbes survive and thrive, Mitsch says. "In a way it's totally opposite to conventional engineering."

Due to the huge variety of techniques, pollution loads, and environmental conditions involved in constructed wetlands, it's difficult to generalize about the pollution reductions this technology can provide. But Mitsch offers a couple of examples. A two-acre wetland in Logan County, Ohio, has been treating runoff from 17 acres of farmland since 1999. The wetland reduces nitrate nitrogen by 40% and total phosphorus by 50%; both chemicals are major causes of eutrophication in surface waters in agricultural areas. And 13 acres of wetlands at Mitsch's Olentangy River Wetland Research Park have been removing nitrogen, phosphorus, and sediments from the polluted river water for almost a decade with no sign of reduced capacity. Increasing degradation capacity is easy: "If you want to get a better reduction . . . you just design a bigger wetland," Mitsch explains.

Pioneering the pristine. The Arcata Marsh and Wildlife Sanctuary (above and left) was constructed in part to restore a coastal marsh that had been drained and destroyed 100 years earlier.

Environmental Services, City of Arcata

One of the pioneering American examples of large-scale ecological engineering, the Arcata (California) Marsh and Wildlife Sanctuary, is a restored wetland adjacent to the city's wastewater treatment plant. The project, opened in 1985 and built at a cost of less than $700,000, was developed as an alternative to a proposed more expensive expansion to the treatment plant. About 30 acres of the 307-acre marsh are devoted to final treatment, or "polishing," of wastewater that has passed through a conventional treatment plant. The balance is a restoration of the coastal marsh that had been drained and destroyed more than 100 years earlier.

Arcata's treatment wetland proves two things. First, constructed wetlands can be beautiful—the restored marsh is located on an old industrial site, and appears prominently on the city's homepage. And second, they sometimes are the cheapest alternative. "Very often, you can show that if you solve the problem ecologically, with nature's tools, it's less costly than if you use human monitors, pipes, pumps, and especially chemicals," says Mitsch. "And we [humans] have this basic desire to have natural systems around us. So if we can use something that's akin to nature to solve our problems, it's a double-win situation."

Indeed, constructed wetlands technology may be the answer to a complicated, costly question. In volume 44, issue 11–12 (2001) of *Water Science & Technology*, civil engineering professor B.S.O. de Ceballos of the Federal University of Paraíba, Brazil, and colleagues tested constructed wetlands on a highly polluted river in Paraíba State. The researchers wrote, "Due to simplicity of their design, operation and maintenance, [constructed wetlands] seem nowadays to be the most promising technology to be applied in developing countries."

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Suggested Reading

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